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REDISTRIBUTION AND FISCAL UNCERTAINTY SHOCKS*

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This article studies the impact of fiscal uncertainty shocks. In micro data, noncapital holders reduce consumption persistently in response to an increase in fiscal uncertainty whereas capital holders do not. Motivated by this evidence, I introduce limited capital market participation and show that it magnifies the fall in economic activity due to a fiscal uncertainty shock and induces macroeconomic comovement. This is because the limited participation model captures individual uncertainty about redistribution. When agents are ambiguity averse, this uncertainty about redistribution has first-order effects. As a result, the model successfully matches the empirical responses of macro and household variables.

1. INTRODUCTION

In this article, I study a business cycle model with limited capital market participation and Knightian uncertainty that can successfully match the empirical responses of macro aggregates and household-level variables to fiscal uncertainty shocks. With limited capital market participation, the model captures individual uncertainty about redistribution that is absent in representative agent models. When agents are ambiguity averse, this uncertainty about redistribution has first-order effects because it shows up as heterogeneous worst-case scenarios. Thus, household heterogeneity significantly magnifies the fall in economic activity due to a capital income tax uncertainty shock and induces comovement of macro variables.

To study the empirical effects of fiscal uncertainty shocks, I first estimate a structural vector autoregression (VAR) using measured fiscal volatilities. I include in the VAR not only standard macro variables, but also household-level consumption measured from the Consumer Expenditure Survey (CEX). According to the VAR, output, consumption, investment, and hours all drop in response to an increase in the volatility of innovations to capital income tax. In addition, real wages decline and the economy experiences a mild deflation. The capital income tax volatility shock is quantitatively relevant: for example, at eight-quarter-ahead horizon, it explains 21% of forecast error variance of real per capita GDP. At the household level, the impulse response is heterogeneous. In particular, while noncapital holders reduce their consumption persistently, capital holders do not. This suggests that the macroeconomic contraction after the capital income tax uncertainty shock could be at least partially driven by the consumption cut by noncapital holders.

Motivated by this finding, I construct a New Keynesian business cycle model featuring limited capital market participation. In addition, I assume that agents have recursive multiple prior preferences and perceive uncertainty not only as risk but also as ambiguity (Knightian

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uncertainty).[2] Under this preference representation, agents lack confidence in assigning probabilities to relevant events and act *as if* they evaluate plans according to the worst-case scenario drawn from a set of multiple beliefs. As in Bianchi et al. (2017) and Ilut and Saijo (2020), the belief sets are tied to the measured volatilities of these fiscal instruments and are parameterized by intervals of conditional means. In turn, as in Fernández-Villaverde et al. (2015) and Born and Pfeifer (2014), each fiscal instrument is allowed to display time-varying volatility in its innovations. Hence, a fiscal volatility shock means an increase in the width of the intervals.

The limited capital market participation model matches the data well. As in the data, the model reproduces sizable and simultaneous falls in output, consumption, investment, and hours while also successfully matching the dynamics of prices such as real wages and inflation. In contrast, the representative agent counterpart of the model in which all agents participate in the capital market misses key features of the data. In particular, macro quantities such as output and hours fall too little, consumption does not fall initially, and real wages stay constant.

To understand the mechanism, first consider the representative agent model. An increase in uncertainty about the capital tax rate increases the width of the set of the conditional mean for the one-period-ahead capital tax and thus the representative household acts *as if* future capital tax rates are higher. Due to a lower after-tax return on capital, households reduce their investment. In contrast, consumption does not fall because it becomes cheaper relative to investment.[3] Because of the intertemporal substitution of labor supply, households work less: a lower perceived after-tax return on investment reduces the return on working. However, since consumption does not fall, the reduction in overall aggregate demand is mitigated and thus equilibrium employment and output decline only mildly.

Next, consider a model with limited capital market participation. The key feature of the limited capital market participation model is that the worst-case beliefs are heterogeneous. Capital holders fear a higher future capital tax rate. Noncapital holders, in contrast, act *as if* the future capital tax is lower. Lower capital tax makes noncapital holders worse off since, assuming transfers are equally distributed across households, lump-sum transfers are lower (lump-sum taxes are higher) because of lower government revenue. As a result of this perceived negative income effect, noncapital holders reduce their consumption. Because the consumption cut by noncapital holders outweighs the mild consumption increase by capital holders, aggregate consumption declines. Thus, aggregate demand declines and markups increase due to sticky prices. The increase in markups leads to lower wages and labor and as a result output falls significantly. To sum up, in the heterogeneous household model, noncapital holders perceive a negative income effect because the model captures individual uncertainty about redistribution that is absent in the representative agent model. Because this individual uncertainty manifests itself as heterogeneous worst-case scenarios, household heterogeneity has first-order effects: relative to the representative agent model, a capital income tax uncertainty shock generates a sizable fall in output, investment, consumption, and hours.

The rest of the article is organized as follows: After reviewing the relevant literature, in Section 2, I use a structural VAR to investigate the empirical effects of fiscal uncertainty shocks on macro aggregates and household-level consumption. In Section 3, I introduce the model. Section 4 describes the solution procedure and the Bayesian impulse-response matching method to estimate the model. Section 5 presents the results and Section 6 concludes. Additional details and results are collected in the Online Appendix.

[2] The multiple prior utility was axiomatized by Gilboa and Schmeidler (1989). Epstein and Schneider (2003) introduce a recursive version that is consistent with dynamic optimization.

[3] It is important to point out that this is not a generic feature of the representative agent model. For example, in Fernández-Villaverde et al. (2015) and Born and Pfeifer (2014), fiscal uncertainty shocks generate a reduction in consumption. However, as I show below, using a Fernández-Villaverde et al. (2015) parameterization and assuming expected utility, the model understates the decline in real activity compared to the VAR and counterfactually predicts an increase in inflation and the nominal interest rate.

1.1. *Relation to the Literature.* This article is related to two strands of literature. First, this article is most closely related to Fernández-Villaverde et al. (2015) and Born and Pfeifer (2014). Both papers study the effects of fiscal uncertainty shocks using a representative agent New Keynesian model. I introduce limited capital market participation and show that household heterogeneity has important implications for aggregate outcomes. Bachmann et al. (2019) and Bretscher et al. (2017) also study the interaction of household heterogeneity and fiscal uncertainty. Their focuses are different from those in this article. In Bachmann et al. (2019), they use an incomplete-market real business cycle model a lá Krusell and Smith (1998) to study the welfare and distributional consequences of permanently eliminating fiscal uncertainty. Bretscher et al. (2017) estimate a New Keynesian model with a savers–spenders type heterogeneity to analyze the implications of fiscal uncertainty shocks on the term structure of interest rates and bond risk premia. My goal is to investigate the short-run impact of fiscal uncertainty shocks on macroeconomic variables. Bianchi and Melosi (2017) consider the implications of policy uncertainty regarding how government debt will be stabilized. Interestingly, they show that policy uncertainty of this kind actually mitigates recessions at the cost of increased future macroeconomic volatility. Since how strongly the government tries to stabilize government debt (for example, through inflating it away) would likely have substantial distributional consequences, an introduction of ambiguity aversion and household heterogeneity into their framework may have important effects. More broadly, this article is part of a rapidly-growing literature that is interested in how uncertainty shocks affect macroeconomic fluctuations. Examples in this literature include Bloom (2009), Fernández-Villaverde et al. (2011), Basu and Bundick (2017), Arellano et al. (2019), Bachmann and Bayer (2013), and Christiano et al. (2014).

I also relate to the emerging literature on Knightian uncertainty and business cycles, such as Ilut and Schneider (2014), Bianchi et al. (2017), and Ilut and Saijo (2020). Two papers are particularly relevant in this literature. Methodologically, I build on the work by Ilut et al. (2016), who develop an algorithm to solve linear, dynamic, heterogeneous agent models with Knightian uncertainty and study the properties of a borrower–lender model. I apply their method to a New Keynesian environment with heterogeneous households facing fiscal uncertainty shocks. Michelacci and Paciello (2020) consider the impact of imperfectly credible monetary policy announcements in a New Keynesian model where, as in Ilut et al. (2016), households are ambiguity averse and have heterogeneous net financial wealth. In their paper, the announcement of a future policy loosening could lead to a contraction in economic activity due to the perceived negative income effect because the economy behaves as if the aggregate net worth is lower. In this article, limited capital market participation amplifies the impact of capital income tax uncertainty shocks because the economy behaves as if the government budget constraint does not hold in the aggregate, since both types of agents act as if they will be losers.

2. VAR EVIDENCE: MACRO AND MICRO-LEVEL RESPONSES TO FISCAL UNCERTAINTY SHOCKS

To examine the empirical evidence on the impact and propagation of fiscal volatility shocks, I conduct a structural VAR analysis similar to those in Fernández-Villaverde et al. (2015), where I augment a quarterly VAR with fiscal volatility processes. The main difference from Fernández-Villaverde et al. (2015) is that, I include not only standard macro variables but also household-level consumption in the VAR. This allows me to study the extent to which households react differently to fiscal uncertainty shocks depending on their types.

I first specify the data-generating process for fiscal rules that describe the law of motion of four main fiscal policy instruments: the ratio of government spending to output, g_t, consumption tax rate, $\tau_{c,t}$, labor income tax rate, $\tau_{h,t}$, and capital income tax rate, $\tau_{k,t}$. Each instrument follows the process described below:

$$(1) \quad \hat{x}_t = \rho_x \hat{x}_{t-1} + \phi_{x,Y} \hat{Y}_{t-1} + \phi_{x,B} \ln\left(\frac{B^g_{t-1}}{Y_{t-1}} \Big/ \frac{B^g}{Y} \right) + \exp(\sigma_{x,t-1}) u_{x,t}, \qquad u_{x,t} \sim N(0,1)$$

for $x \in \{g, \tau_c, \tau_h, \tau_k\}$. I use the hat symbol to denote log-deviations from the steady state. The fiscal rule (1) embeds two feedbacks. First, there is an "automatic stabilizer" component that allows an instrument to respond to the log-deviation of lagged output, Y_{t-1}, from the steady state ($\phi_{g,Y} < 0$ and $\phi_{\tau_x,Y} > 0$). Second, an instrument may also respond to the log-deviation of debt-to-GDP ratio, B^g_{t-1}/Y_{t-1}, from its steady-state value ($\phi_{g,B} < 0$ and $\phi_{\tau_x,B} > 0$). Following Fernández-Villaverde et al. (2015) and Born and Pfeifer (2014), I allow for stochastic volatility in innovations of each fiscal instrument. I assume the stochastic volatility component follows an exogenous AR(1) process:

$$\sigma_{x,t} = (1 - \rho_{\sigma_x})\sigma_x + \rho_{\sigma_x}\sigma_{x,t-1} + \zeta_x e_{x,t}, \tag{2}$$

where $e_{x,t} \sim N(0, 1)$. I estimate the fiscal rule and volatility process (1) and (2) using the particle filter, where I set flat priors for all parameters. I use the tax rates and spending series of the consolidated government sector (1970:Q2–2014:Q2) from Fernández-Villaverde et al. (2015). Columns labeled "Prior" in Table 2 report the parameter estimates of the fiscal volatility processes.[4]

Time-varying fiscal volatility appears crucial. For example, consider the capital income tax. At the mean estimate, the steady-state standard deviation of an innovation to capital income tax is ($100 \exp(\bar{\sigma}_{\tau_k}) =$) 2 percentage points. A two-standard-deviations capital income tax uncertainty shock, assuming that the capital income tax volatility is at the steady state, raises the standard deviation of the innovation to ($100 \exp(\ln(0.02) + 2 \times 0.40) =$) 4.5 percentage points. Furthermore, since the autoregressive component of the capital income tax *level* is very persistent at $\rho_{\tau_k} = 0.99$, even if the volatility increase is temporary, agents expect that changes that occurred in capital income tax would have lasting effects. As I show in Figure A1 in the Online Appendix, in recent years there have been several episodes where time-varying fiscal volatility has been high, with the exception of government spending volatility. For instance, capital income tax volatility has increased roughly by 100% during the early 2000s, which experienced the 2001 recession, the 9/11 attack, and the Bush tax cuts, and during the late 2000s, which saw the Great Recession. Capital tax volatility increased by around 50% from 2011 to 2013, when the fiscal cliff took place. Labor income tax volatility spiked around the same periods as the rises in capital income tax volatility happened, whereas consumption tax volatility climbed in the early 1990s. These changes in measured fiscal volatility resemble actual changes in fiscal uncertainty faced by agents in the U.S. economy. Indeed, as I show in Section A of the Online Appendix, the fiscal volatility series is positively correlated with the policy uncertainty index by Baker et al. (2016) and survey forecast dispersions.

I estimate four-lag recursive VARs with linear time trends where I include the following variables: (i) the filtered fiscal volatility, (ii) log real per capita GDP, (iii) log real per capita consumption, (iv) log real per capita investment, (v) log per capita hours worked, (vi) log real wage, (vii) GDP deflator inflation, (viii) Federal funds rate, (ix) log real per capita consumption of households who own stocks, and (x) log real per capita consumption of households who do not own stocks. The ordering of the variables reflects the idea that fiscal uncertainty shocks are exogenous. I use filtered volatility, which conditions on information up to period t, instead of smoothed volatility, which uses all the information available up to the end of the sample, so that the timing is consistent with that of the VAR. I estimate four separate VARs for each fiscal instruments, where the only difference among the VARs is the fiscal volatility process that enters as observables.[5] The sample period is 1982:Q1–2008:Q3. The sample starts after the Volcker disinflation in order to circumvent parameter instabilities related to monetary policy. Similarly, in order to avoid complications arising from the zero lower bound (ZLB), I trim the observations after 2008:Q4.

[4] As I explain in detail below, I use the particle filter estimates as priors for the joint estimation of fiscal processes (1) and (2) and other structural parameters.

[5] I also estimated a VAR where the fiscal volatility processes for all instruments enter jointly. The results are very similar.

To construct household-level consumption series, I use the CEX, collected by the Bureau of Labor Statistics (BLS). The CEX consists of two surveys, the Quarterly Interview Survey and the Diary Survey, and provides information on household expenditures, income, employment, and other characteristics. I use the Interview portion of the survey, available for download at the Web site of Inter-university Consortium for Political and Social Research, University of Michigan. In the survey, each household is interviewed five times over a 15-month period. The initial interview collects demographic and family information. The second through fifth interviews (total of four interviews) collect information for the three months prior to the interviews. All households are asked about their financial information in the fifth interview.

I construct a pseudo-panel by averaging household consumption identified by their asset-holding status.[6] Consumption is defined as expenditures on nondurables and services.[7] Households are asked about their amounts in "Checking accounts, brokerage accounts, and other similar accounts," "Savings accounts at banks, savings and loans, credit unions, etc.," "Stocks, bonds, mutual funds, and other such securities," and "U.S. savings bonds." In the baseline analysis, I compare households that hold stocks or bonds to those that do not. I classify households with positive responses to "Stocks, bonds, mutual funds, and other such securities" as capital holders and the rest as noncapital holders.[8] I do not classify households with positive responses to only "U.S. savings bonds" as capital holders because income from U.S. savings bonds are not taxed as capital income. In the data (1982:Q1–2008:Q3), the mean number of observations per quarter is 4,221 for all households. The number of observations per quarter for households who are classified as capital holders is 618; thus, about 15% of households are capital holders.

Figure 1 plots the VAR responses of aggregate variables to a two-standard-deviations increase in capital income tax volatility.[9] According to the VAR, an increase in capital income tax volatility generates a fall in real activity, causing an estimated 0.4 percentage mean decline in output a year and a half after the shock and similar reductions in consumption and hours. The reductions in macro quantities are statistically significant for most horizons. The real wage and the nominal interest rate also fall and inflation declines mildly. The capital income tax volatility shock is empirically relevant for macro variables. For example, at eight-quarter-ahead (12-quarter-ahead) horizon, the shock explains 21% (21%), 17% (20%), 18% (15%), and 22% (16%) of forecast error variance of output, consumption, investment, and hours, respectively.[10]

Figure 2 plots the VAR responses of CEX consumption for capital holders and noncapital holders. Capital holders and noncapital holders react quite differently. In particular, while noncapital holders reduce their consumption, capital holders' response is insignificant for most horizons. This suggests that the macroeconomic contraction after the capital income tax uncertainty shock could be at least partially driven by the consumption cut by noncapital holders. To further understand the heterogeneous impulse responses at the household level and their implications for aggregate variables, in the next section I pursue a structural approach.

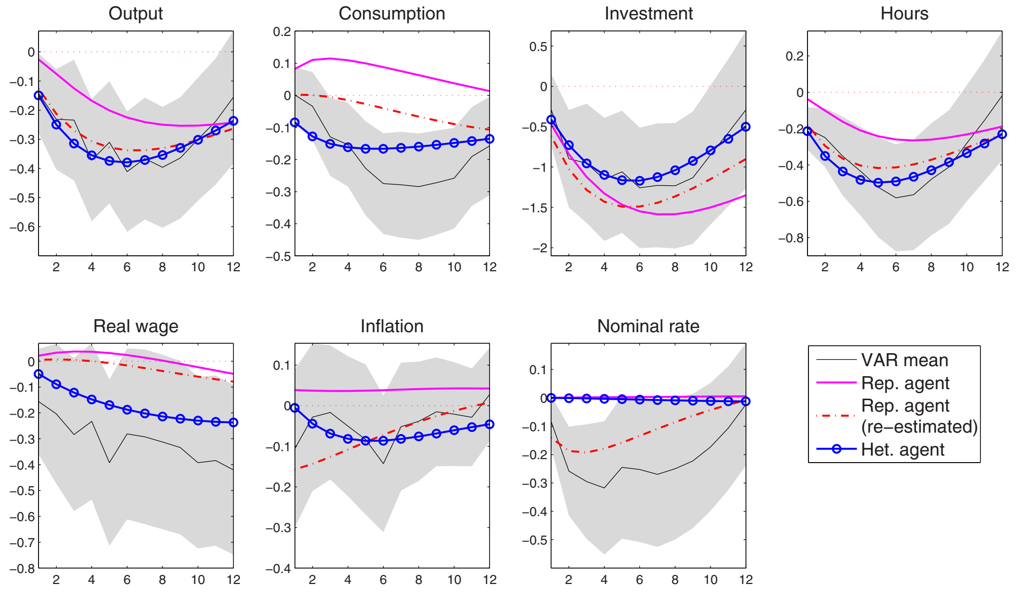
[6] As recommended by the BLS, I use population weights. The average consumption is deflated using the CPI and then seasonally adjusted using the X-12-ARIMA filter. Using the GDP deflator gives very similar results.

[7] My consumption measure includes expenditures on food, alcoholic beverages, utilities, fuels, public services, household operations, apparel, gasoline and motor oil, public transportation, entertainment, personal care, reading, and tobacco.

[8] To mitigate the issue of simultaneity regarding consumption and capital market participation decision, I define capital holders as households that were holding stocks or bonds *a year before* and noncapital holders as households that were not holding stocks or bonds *a year before* at each point in time. To do this, I employ two additional variables in the CEX. The first variable asks whether a household's amount of stock or bond holding remained the same, increased, or decreased from a year prior. The second variable asks the difference in the estimated market value of a household's stock or bond holding from a year ago.

[9] I construct confidence bands using a bootstrap procedure, taking into account the fact that the filtered volatility is a generated regressor. This way, the confidence bands are consistent with the Bayesian impulse-response matching below, where fiscal parameters in (1) and (2) are treated as random variables.

[10] The other shocks are less important. For example, government spending, consumption income tax, and labor income tax volatility shocks explain 2%, 8%, and 9%, respectively, of eight-quarter-ahead forecast error variance.



NOTES: The figure reports the impulse responses to a two-standard-deviations increase in σ_{τ_k} (capital income tax volatility). The units are in percents (annual percentage points for inflation and nominal rate). The black lines are the mean responses from the VAR and the shaded areas are the 95% confidence band. The blue lines with circles are the responses from the baseline heterogeneous agent model with limited capital market participation. The purple lines are the responses from the representative agent model with full capital market participation where I set the share of noncapital holders χ to 0, while holding other parameters at the estimated values from the limited participation model. The red dashed lines are the responses from the representative agent model, where I reestimate the parameters while imposing the constraint that the share of noncapital holders χ is 0.

FIGURE 1

CAPITAL INCOME TAX UNCERTAINTY SHOCK: AGGREGATE VARIABLES
[COLOR FIGURE CAN BE VIEWED AT WILEYONLINELIBRARY.COM]

3. MODEL

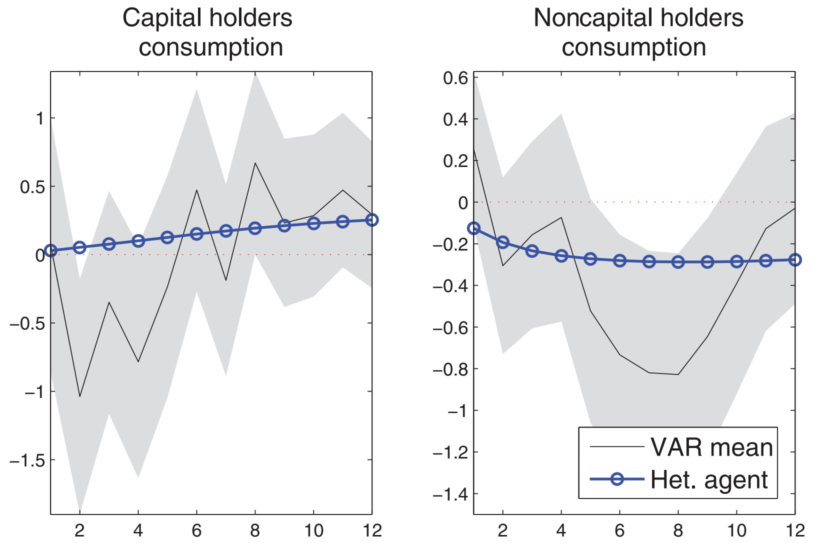
I study a New Keynesian business cycle model in the tradition of Christiano et al. (2005) and Smets and Wouters (2007) to evaluate the impact and transmission of fiscal uncertainty shocks. The framework is a natural environment for my quantitative analysis since it has now become the foundation of applied research in both academic and government institutions. I introduce two additional features. First, households are ambiguity averse as in Ilut and Schneider (2014) and face Knightian uncertainty about fiscal policies. Second, motivated by the heterogeneous impulse responses in Figure 2, I assume limited capital market participation. In the following, letters without a time subscript refer to steady-state values.

3.1. *Fiscal Shocks and Fiscal Uncertainty Shocks.* Agents are not confident about the innovations $u_{x,t}$ to the fiscal instrument processes (1). As a result, they entertain a set of conditional means $\mu_{x,t}$ centered on the benchmark mean of zero:

$$\hat{x}_{t+1} = \rho_x \hat{x}_t + \phi_{x,Y}\hat{Y}_t + \phi_{x,B} \ln\left(\frac{B_t^g}{Y_t}\Big/\frac{B^g}{Y}\right) + \mu_{x,t} + \exp(\sigma_{x,t})u_{x,t+1}, \tag{3}$$

where $\mu_{x,t}$ is a set of intervals $\mu_{x,t} \in [-a_{x,t}, a_{x,t}]$. Agents only consider the conditional means $\mu_{x,t}$ that are sufficiently close to the long run average of zero in the sense of relative entropy:

$$\frac{\mu_{x,t}^2}{2\{\exp(\sigma_{x,t})\}^2} \leq \frac{1}{2}\eta^2, \tag{4}$$



NOTES: The figure reports the impulse responses to a two-standard-deviations increase in σ_{τ_k} (capital income tax volatility). The units are in percents (annual percentage points for inflation and nominal rate). The black lines are the mean responses of CEX consumption from the VAR and the shaded areas are the 95% confidence band. The blue lines with circles are the responses from the baseline heterogeneous agent model with limited capital market participation. The CEX consumption responses are *not* included as targets in the estimation of the model.

FIGURE 2

CAPITAL INCOME TAX UNCERTAINTY SHOCK: HOUSEHOLD-LEVEL CONSUMPTION
[COLOR FIGURE CAN BE VIEWED AT WILEYONLINELIBRARY.COM]

where the left-hand side is the relative entropy between two normal distributions that share the same variance $\{\exp(\sigma_{x,t})\}^2$ but have different means ($\mu_{x,t}$ and zero), and $\eta \geq 0$ is a parameter that controls the size of the entropy constraint. The entropy constraint (4) results in a set $[-a_{x,t}, a_{x,t}]$ for $\mu_{x,t}$ in (3) that is given by

$$a_{x,t} = \eta \exp(\sigma_{x,t}). \tag{5}$$

Hence, when volatility increases, agents become less confident and consider a wider set of means.

In this article, I deliberately focus on ambiguity about fiscal variables. Introducing Knightian uncertainty to productivity (as in Ilut and Schneider, 2014) or other shocks would not affect the main conclusions of the article. First, as I describe in detail below, I estimate the model using impulse responses to fiscal uncertainty shocks only. Thus, impulse responses to other shocks will not directly affect the parameter estimates. Second, adding ambiguity about other variables affects the decision rules through existing coefficients and not as independent terms, and hence will only have a second-order impact.[11]

3.2. *Households.* There is a unit mass of ambiguity-averse households. A fraction $1-\chi$ of households have access to capital markets. I call them capital holders (hence the superscript "c"). The rest of the χ fraction of households do not hold capital. I call them noncapital holders (hence the superscript "n"). The standard representative agent model obtains when $\chi = 0$.

Capital holders have recursive multiple priors utility (Epstein and Schneider, 2003). The multiple priors specification captures agents' lack of confidence in probability assessments. Collect the exogenous state variables in a vector $s_t \in S$. A household consumption plan C^c

[11] Ambiguity about other variables affects existing coefficients because it changes agents' perceived steady state where the worst case actually realizes.

gives, for every history s^t, the consumption of the final good $C^c_t(s^t)$ and the amount of hours worked $H^c_t(s^t)$. For a given consumption plan C^c, utility is defined recursively by

$$(6)\qquad U^c_t(C^c; s^t) = \ln(C^c_t - bC^c_{t-1}) - \frac{(H^c_{i,t})^{1+\phi}}{1+\phi} + \beta d_t \min_{\mu_{x,t}\in[-a_{x,t},a_{x,t}],\forall x} E^{\mu}[U^c_{t+1}(C^c; s^t, s_{t+1})],$$

where b is the consumption habit, ϕ is the inverse of Frisch labor supply elasticity, and β is the steady-state subjective discount factor. d_t is a discount factor shock that follows:

$$\ln d_t = \rho_d \ln d_{t-1} + \epsilon_{d,t}, \qquad \epsilon_{d,t} \sim N\left(0, \sigma^2_d\right).$$

For each fiscal instrument x, agents entertain a set of conditional means $\mu_{x,t} \in [-a_{x,t}, a_{x,t}]$. Because agents are not willing to integrate over their beliefs and narrow down each set to a singleton, they take a precautionary approach and act *as if* the true data generating process is drawn from the worst-case belief that minimizes their expected continuation utility. The model reduces to the standard rational expectations model when each set is a singleton.

Capital holders maximize their utility subject to the budget constraint:

$$(7)\qquad (1+\tau_{c,t})P_tC^c_t + P_tI^c_t + P_tB^c_t \le (1-\tau_{h,t})P_tW_{i,t}H^c_{i,t} + (1-\tau_{k,t})P_tR^k_tK^c_{t-1} + P_t\tau_{k,t}\delta K^c_{t-1} + R_{t-1}P_{t-1}B^c_{t-1} + Q^c_{i,t} + D^c_t + P_tT^c_t,$$

and the capital accumulation equation:

$$(8)\qquad K^c_t = (1-\delta)K^c_{t-1} + \left\{1 - \frac{\kappa}{2}\left(\frac{I^c_t}{I^c_{t-1}} - \gamma\right)^2\right\}I^c_t,$$

where P_t is the price level, I^c_t is investment, B^c_t is the real bond holding, W_t is the real wage, R^k_t is the real rental rate of capital, R_t is the nominal interest rate, D^c_t are dividends from intermediate firms, and T^c_t is a lump-sum transfer (or tax if it takes a negative value). I assume that households buy securities, whose payoff $Q^c_{i,t}$ is contingent on whether they can reoptimize their wage.[12] $\tau_{c,t}$, $\tau_{h,t}$, and $\tau_{k,t}$ are the consumption, labor, and capital income tax rates, respectively. I incorporate depreciation allowances, where δ is the depreciation rate. I assume an investment adjustment cost where $\kappa > 0$ is a parameter that controls the size of the adjustment cost and γ is the rate of deterministic labor-augmenting technology growth.

Noncapital holders also have recursive multiple priors utility:

$$(9)\qquad U^n_t(C^n; s^t) = \ln(C^n_t - bC^n_{t-1}) - \frac{(H^n_{i,t})^{1+\phi}}{1+\phi} + \beta d_t \min_{\mu_{x,t}\in[-a_{x,t},a_{x,t}],\forall x} E^{\mu}[U^n_{t+1}(C^n; s^t, s_{t+1})],$$

and their budget constraint is

$$(10)\qquad (1+\tau_{c,t})P_tC^n_t + P_tB^n_t \le (1-\tau_{h,t})P_tW_{i,t}H^n_{i,t} + R_{t-1}P_{t-1}B^n_{t-1} + Q^n_{i,t} + P_tT^n_t - \frac{\upsilon}{2}\left(\frac{B^n_t}{Y_t}\right)^2 P_tY_t.$$

[12] Because of the idiosyncratic nature of the timing of wage reoptimization, households are heterogeneous with respect to the wage rate and hours regardless of their capital market participation status. To ensure tractability, I introduce state-contingent securities so that households are homogeneous with respect to consumption and asset holdings *within* their types. However, to preserve heterogeneity in consumption and asset holdings *across* types, I assume that capital holders trade the securities among capital holders and noncapital holders trade the securities among noncapital holders.

Noncapital holders do not participate in the capital market but have access to risk-less bonds.[13] The last term in the budget constraint is the quadratic bond-holding cost, whose size is controlled by the parameter $\upsilon > 0$. This cost induces stationarity in an otherwise nonstationary equilibrium bond holdings (Schmitt-Grohe and Uribe, 2003).[14]

3.3. *Firms.* In each period t, the final goods, Y_t, are produced by a perfectly competitive representative firm that combines a continuum of intermediate goods, indexed by $j \in [0, 1]$, with technology

$$Y_t = \left[\int_0^1 Y_{j,t}^{\frac{\theta_p - 1}{\theta_p}} dj\right]^{\frac{\theta_p}{\theta_p - 1}}.$$

$Y_{j,t}$ denotes the time t input of intermediate good j and θ_p controls the price elasticity of demand for each intermediate good. The demand function for good j is

$$Y_{j,t} = \left(\frac{P_{j,t}}{P_t}\right)^{-\theta_p} Y_t,$$

where P_t and $P_{j,t}$ denote the price of the final good and intermediate good j, respectively. P_t is related to $P_{j,t}$ via the relationship

$$P_t = \left[\int_0^1 P_{j,t}^{1-\theta_p} dj\right]^{\frac{1}{1-\theta_p}}.$$

The intermediate-goods sector is monopolistically competitive. In period t, each firm j rents $K_{j,t}$ units of capital stock from the household sector and buys $H_{j,t}$ units of aggregate labor input from the employment sector to produce intermediate good j using technology

$$Y_{j,t} = z_t K_{j,t}^{\alpha} (\gamma^t H_{j,t})^{1-\alpha},$$

where z_t is an aggregate technology shock that follows:

$$\ln z_t = \rho_z \ln z_{t-1} + \epsilon_{z,t}, \qquad \epsilon_{z,t} \sim N\left(0, \sigma_z^2\right).$$

Intermediate firms face a Calvo-type price-setting friction: in each period t, a firm can reoptimize its intermediate-goods price with probability $(1 - \xi_p)$. Firms that cannot reoptimize index their price according to the steady-state inflation rate, π.

3.4. *Employment.* In each period t, a perfectly competitive representative employment agency hires labor from households to produce an aggregate labor service, H_t, using technology

$$H_t = \left[\int_0^1 H_{i,t}^{\frac{\theta_w - 1}{\theta_w}} di\right]^{\frac{\theta_w}{\theta_w - 1}},$$

[13] This is in contrast to the hand-to-mouth households in Galí et al. (2007), who do not have access to bonds. That noncapital holders have access to bonds is crucial for the transmission mechanism, as it makes noncapital holders forward-looking and react to changes in worst-case scenarios.

[14] The cost also captures the notion that noncapital holders tend to have less access to intertemporal smoothing devices compared to capital holders. For example, in the CEX data 52% and 37% of noncapital holders hold checking and savings accounts, respectively. In contrast, 87% and 73% of capital holders hold checking and savings accounts, respectively.

where $H_{i,t}$ denotes the time t input of labor service from household i and θ_w controls the price elasticity of demand for each household's labor service. The agency sells the aggregated labor input to the intermediate firms for a nominal price of W_t per unit. Households (both capital holders and noncapital holders) face a Calvo-type wage-setting friction: in each period t, a household can reoptimize its nominal wage with probability $(1 - \xi_w)$. Households that cannot reoptimize index their wage according to the steady-state wage growth rate, $\gamma\pi$.

3.5. *Aggregation, Government, and Resource Constraint.* Aggregate consumption, hours, investment, and capital are defined as:

$$C_t \equiv \chi C_t^n + (1-\chi)C_t^c,$$
$$H_t \equiv \chi H_t^n + (1-\chi)H_t^c,$$
$$I_t \equiv (1-\chi)I_t^c,$$
$$K_t \equiv (1-\chi)K_t^c.$$

The resource constraint is

$$C_t + I_t + G_t + \frac{\upsilon}{2}\left(\frac{B_t^n}{Y_t}\right)^2 Y_t = Y_t,$$

where G_t is government spending.

The central bank follows a Taylor rule with interest-rate smoothing:

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R}\right)^{\rho_R}\left\{\left(\frac{\pi_t}{\pi}\right)^{\phi_\pi}\left(\frac{Y_t}{\gamma^t Y}\right)^{\phi_Y}\right\}^{1-\rho_R}\exp(\epsilon_{R,t}), \tag{11}$$

where ρ_R is the persistence of the rule and ϕ_π and ϕ_Y are the size of the policy response to the deviation of inflation and output from their steady states, respectively. π_t is the current inflation rate and $\epsilon_{R,t}$ is a monetary policy shock that follows $\epsilon_{R,t} \sim N(0, \sigma_R^2)$.

The government budget constraint is

$$T_t + G_t = B_t^g - R_{t-1}\frac{B_{t-1}^g}{\pi_t} + \tau_{c,t}C_t + \tau_{h,t}\int_0^1 W_{i,t}H_{i,t}di + \tau_{k,t}(R_t^k - \delta)K_{t-1},$$

where $T_t \equiv \chi T_t^n + (1-\chi)T_t^c$ and B_t^g is the real government bond. The transfers are equally distributed across households: $T_t = T_t^n = T_t^c$. I assume that the real government bond is related to the previous period transfer according to

$$\hat{B}_t^g = \rho_B \hat{B}_{t-1}^g + \phi_{B,Y}\hat{Y}_{t-1} + \phi_{B,T}\hat{T}_{t-1}, \tag{12}$$

where $\phi_{B,T}$ is restricted to a value that makes the government bond nonexplosive. The lump-sum transfers adjust so that the government budget constraint is satisfied. Finally, the bond market clearing condition is

$$\chi B_t^n + (1-\chi)B_t^c = B_t^g.$$

4. SOLUTION AND PARAMETERIZATION

4.1. *Solution.* The equilibrium conditions that characterize the economy are listed in Section C in the Online Appendix. To solve the model, I follow the methodology developed in

TABLE 1
PARAMETERS FIXED PRIOR TO ESTIMATION

	Description	Source	Value
γ	Technological growth rate	Average per capita GDP growth	1.004
α	Capital share	Standard value	0.3
β	Discount factor	Standard value	0.99
δ	Depreciation rate	Standard value	0.025
θ_p	Price elasticity	Born and Pfeifer (2014)	11
θ_w	Wage elasticity	Born and Pfeifer (2014)	11
v	Bond holding cost	Fernández-Villaverde et al. (2011)	0.01

Ilut et al. (2016). They analyze a class of dynamic models with ambiguity-averse agents where agents differ in their worst-case beliefs and recognize that other agents have different worst cases. Because there is heterogeneity in the worst-case beliefs in the steady state, one needs to jointly solve for the steady state and the equilibrium decision rules. The brief outline of the solution method is as follows: First, I log-linearize the equilibrium conditions of the model. Second, I guess the elasticities that map from state variables to endogenous variables. Third, I jointly solve for the steady state and the dynamics taking into account the heterogeneity in worst-case beliefs. I iterate the second and the third steps until the guessed elasticities and the solution coincide. Finally, I verify that the guessed beliefs are indeed the worst-case beliefs by plugging in the decision rules into the linearized value functions. In my model, this can be done simply by checking that both capital holders and noncapital holders become worse off in terms of expected continuation utility when fiscal uncertainty increases.[15]

4.2. *Bayesian Impulse-Response Matching Estimation.* The model is estimated using a Bayesian impulse-response matching method, developed by Christiano et al. (2010a, 2010b). Since this estimation method allows me to squarely focus on fiscal uncertainty shocks and their propagations, I can evaluate directly whether the model can replicate the empirical responses to fiscal uncertainty shocks at the micro and macro level. This will be harder if I use likelihood methods since the estimates could be influenced by model misspecifications in parts of the model that are not directly related to the fiscal uncertainty shocks and their propagations.[16]

In the estimation, my aim is to strike the balance between keeping the exercise focused and letting the data speak as much as possible. Therefore, I fix a small number of parameters prior to the estimation when there is a consensus in the literature regarding their values and estimate parameters that are directly related to the propagation of fiscal uncertainty shocks. The predetermined parameters and their values are summarized in Table 1. I set both θ_p and θ_w to 11, resulting in steady-state markups of 10%. This follows Born and Pfeifer (2014), who set an intermediate value between the ones found in Altig et al. (2011) and Justiniano et al. (2013). I set the bond holding cost v to a small value of 0.01; this helps close the model without substantially affecting its dynamic properties (Fernández-Villaverde et al., 2011). Since the model is solved using a first-order approximation and estimated using an impulse response to the fiscal uncertainty shocks, the parameters for the technology, preference, and monetary policy shocks do not affect the main results of this article. In the Online Appendix, I discuss the parameterization of these shock processes for the exercises in which they are relevant.

Next, consider the estimated parameters. The estimated parameters can be further divided into three groups: (i) the parameters for the fiscal instrument processes (1) and (2), (ii) those for the government bond process (12), and (iii) the rest. Regarding the priors for the fiscal instrument processes, I use the estimates from the particle filter conducted in Section 2. Specifically, for each parameter I compute a kernel density estimate from the simulated posterior and

[15] I provide additional details in Section D of the Online Appendix.
[16] Section F of the Online Appendix provides a detailed description of the estimation method.

use that density estimate as a prior distribution. For simplicity, I assume independent priors. Regarding the government bond process, the prior mean of the steady-state debt-to-GDP ratio B^g/Y is set to 0.64, which is in line with the average debt-to-GDP ratio during the sample period. To form priors for ρ_B, $\phi_{B,Y}$, and $\phi_{B,T}$, I estimate a Bayesian regression of log government debt on log output and log transfers using uniform priors. Then, as in the fiscal instrument processes, for each parameter I compute a kernel density estimate from the simulated posterior and use that estimated density as a prior. Intuitively, I start from the external estimates of the fiscal instruments and debt processes and update those estimates using information from empirical impulse responses to the fiscal uncertainty shocks.

Finally, consider the rest of the parameters. For the inverse Frisch elasticity, I center the prior around 1, which is in line with the recommended value by Chetty et al. (2011). The prior mean of the consumption habit is 0.3, which is consistent with the mean estimate of internal habit in the meta-analysis conducted by Havranek et al. (2017). The prior mean of the investment adjustment cost is set to $\kappa = 3$, which is in the range found in other studies such as Christiano et al. (2005). To determine the prior for the capital market participation rate, I use several sources. According to the household survey conducted in Investment Company Institute (2008), around 50% of U.S. households held stocks. In contrast, as I mentioned in Section 2, around 15% of households hold stocks according to the CEX. The figure may or may not include indirect holdings. The Survey of Consumer Finances (SCF) by the Federal Reserve Board finds that 13.8% of U.S. households held stocks in 2013 but that figure rises to around 50% if we include indirect holdings (Bricker et al., 2014). I center my prior for the share of noncapital holders χ around 0.5 (which implies the capital market participation rate of 50%) with a standard deviation of 0.1. The prior means of the price and wage adjustment parameters are set so that the average durations of price and wage stickiness are four quarters. The priors for the monetary policy rule are formed so that it features inertia, a more than a one-for-one response to inflation and a positive but mild response to output. Finally, the parameter η, which controls the size of the entropy constraint, determines the extent to which changes in volatility translate into changes in ambiguity. Ilut and Schneider (2014) suggest an upper bound of the value of η to be 2, reflecting the idea that the level of ambiguity should not be "too large" in a statistical sense compared to the variability of the data. I reparametrize and estimate 0.5η, for which I set a Beta prior.

In the impulse-response matching estimation, I target the VAR impulse responses of GDP, consumption, investment, hours worked, real wage, inflation, and the Federal funds rate. I do not include CEX consumption responses presented in Figure 2 as targets. This has two advantages. First, the number of observables used in the estimation of the heterogeneous and representative agent models will be the same, which facilitates model comparison. Second, I can use the household-level consumption responses for an external validation of the heterogeneous agent model.

5. RESULTS

I now present the main results. To facilitate comparison with the previous literature (Born and Pfeifer, 2014; Fernández-Villaverde et al., 2015), I mainly focus on an uncertainty shock to the capital income tax rate.

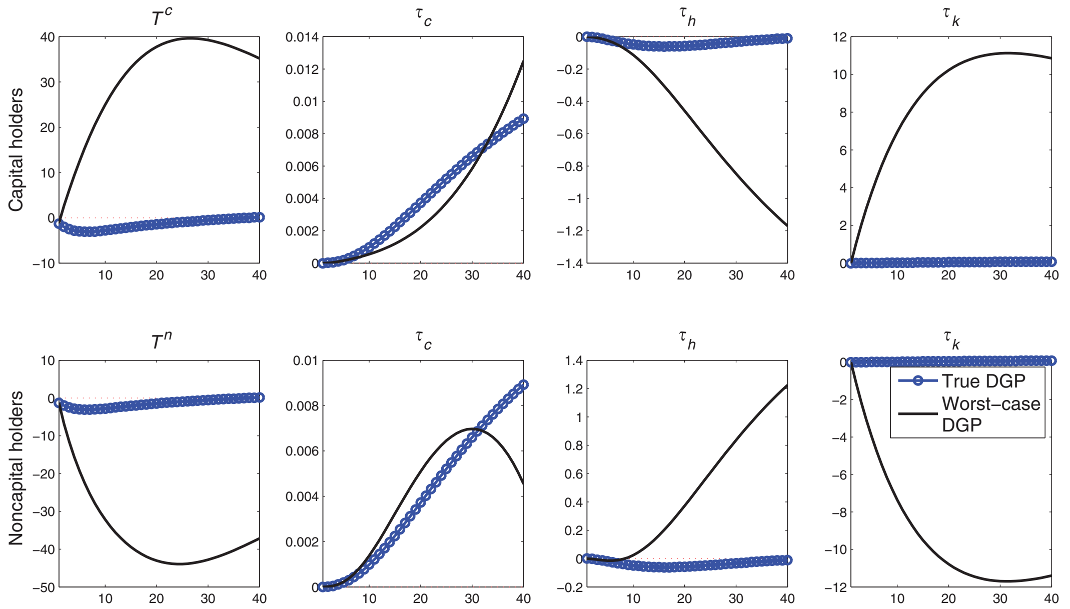
Amplification and Comovement.

Table 2 reports the posterior estimates. For the baseline model with limited capital market participation, the estimates are in line with the New Keynesian literature, featuring relatively large real and nominal rigidities. For example, the estimated average frequencies of price and wage adjustments are five and three quarters, respectively. The estimated share of capital holders is $(1 - \chi =)$ 16%. Interestingly, the estimate is in line with the CEX data and the direct holdings rate in the SCF data. Finally, the persistence parameters for the volatility of fiscal instruments are quite high.

TABLE 2
PARAMETERS ESTIMATED INSIDE THE MODEL

	Prior	Posterior Mean HA	Posterior Mean RA		Prior	Posterior Mean HA	Posterior Mean RA
Preference, technology, and policy parameters							
ϕ	$G(1, 0.5)$	0.14	0.23	b	$B(0.3, 0.05)$	0.43	0.72
		(0.04)	(0.04)			(0.05)	(0.07)
κ	$G(3, 0.5)$	2.25	1.44	χ	$B(0.5, 0.1)$	0.84	0
		(0.37)	(0.27)			(0.02)	
$\frac{1}{1-\xi_p}$	$G(3, 0.3) + 1$	5.45	5.84	$\frac{1}{1-\xi_w}$	$G(3, 0.3) + 1$	3.04	4.37
		(0.25)	(0.42)			(0.20)	(0.33)
ρ_R	$B(0.8, 0.1)$	0.99	0.41	ϕ_π	$N(1.5, 0.1)$	1.88	1.48
		(0.00)	(0.05)			(0.10)	(0.09)
ϕ_Y	$G(0.1, 0.05)$	0.02	0.01	0.5η	$B(0.5, 0.15)$	0.84	0.72
		(0.00)	(0.00)			(0.05)	(0.09)
Government spending							
$\bar{g}$	$K(0.235, 0.002)$	0.234	0.234	ρ_g	$K(0.994, 0.002)$	0.994	0.994
		(0.002)	(0.002)			(0.001)	(0.002)
$\phi_{g,Y}$	$K(0.006, 0.003)$	0.003	0.011	$\phi_{g,B}$	$K(0.004, 0.002)$	0.004	0.001
		(0.001)	(0.005)			(0.001)	(0.001)
$\exp(\sigma_g)$	$K(0.011, 0.001)$	0.011	0.011	ρ_{σ_g}	$K(0.361, 0.250)$	0.731	0.463
		(0.001)	(0.001)			(0.019)	(0.194)
ζ_g	$K(0.181, 0.069)$	0.193	0.220				
		(0.021)	(0.066)				
Consumption tax							
$\bar{\tau}_c$	$K(0.092, 0.001)$	0.092	0.093	ρ_{τ_c}	$K(0.999, 0.001)$	0.998	0.999
		(0.001)	(0.001)			(0.001)	(0.001)
$\phi_{\tau_c,Y}$	$K(0.008, 0.007)$	0.007	0.007	$\phi_{\tau_c,B}$	$K(0.007, 0.002)$	0.008	0.006
		(0.005)	(0.006)			(0.002)	(0.002)
$\exp(\sigma_{\tau_c})$	$K(0.010, 0.001)$	0.019	0.021	$\rho_{\sigma_{\tau_c}}$	$K(0.486, 0.255)$	0.968	0.916
		(0.003)	(0.001)			(0.020)	(0.033)
ζ_{τ_c}	$K(0.460, 0.115)$	0.716	0.751				
		(0.020)	(0.081)				
Labor income tax							
$\bar{\tau}_h$	$K(0.255, 0.019)$	0.257	0.251	ρ_{τ_h}	$K(0.976, 0.011)$	0.965	0.957
		(0.011)	(0.010)			(0.007)	(0.010)
$\phi_{\tau_h,Y}$	$K(0.047, 0.018)$	0.076	0.012	$\phi_{\tau_h,B}$	$K(0.002, 0.001)$	0.001	0.005
		(0.015)	(0.008)			(0.001)	(0.003)
$\exp(\sigma_{\tau_h})$	$K(0.012, 0.003)$	0.009	0.008	$\rho_{\sigma_{\tau_h}}$	$K(0.428, 0.134)$	0.905	0.945
		(0.001)	(0.001)			(0.021)	(0.012)
ζ_{τ_h}	$K(0.944, 0.110)$	0.962	0.843				
		(0.025)	(0.101)				
Capital income tax							
$\bar{\tau}_k$	$K(0.424, 0.011)$	0.430	0.416	ρ_{τ_k}	$K(0.988, 0.010)$	0.984	0.892
		(0.006)	(0.019)			(0.005)	(0.010)
$\phi_{\tau_k,Y}$	$K(0.040, 0.027)$	0.005	0.015	$\phi_{\tau_k,B}$	$K(0.008, 0.004)$	0.016	0.012
		(0.003)	(0.011)			(0.004)	(0.005)
$\exp(\sigma_{\tau_k})$	$K(0.020, 0.003)$	0.018	0.040	$\rho_{\sigma_{\tau_k}}$	$K(0.681, 0.151)$	0.940	0.836
		(0.001)	(0.004)			(0.011)	(0.019)
ζ_{τ_k}	$K(0.403, 0.096)$	0.441	0.508				
		(0.019)	(0.075)				
Government debt							
B^g/Y	$K(0.636, 0.05)$	0.615	0.621	ρ_B	$K(0.987, 0.007)$	0.987	0.985
		(0.032)	(0.053)			(0.004)	(0.009)
$\phi_{B,Y}$	$K(0.161, 0.028)$	0.065	0.160	$\phi_{B,T}$	$K(0.053, 0.038)$	0.005	0.023
		(0.009)	(0.026)			(0.001)	(0.012)

NOTE: B refers to the Beta distribution, N to the Normal distribution, G to the Gamma distribution, and K to the kernel density estimates from the posterior draws. For the priors, the numbers inside the parentheses are the prior means and standard deviations. For the posteriors, the numbers inside the parentheses are the posterior standard deviations.



NOTES: The figure reports the impulse responses to a two-standard-deviations increase in σ_{τ_k} (capital income tax volatility). For transfers (T^c and T^n), the units are in percentage deviations from the steady states. For τ_c, τ_h, and τ_k, the units are in percentage points. The blue lines with circles and the black lines are the responses under the true and the worst-case DGPs (data generating processes), respectively, from the heterogeneous agent model with limited capital market participation.

FIGURE 3

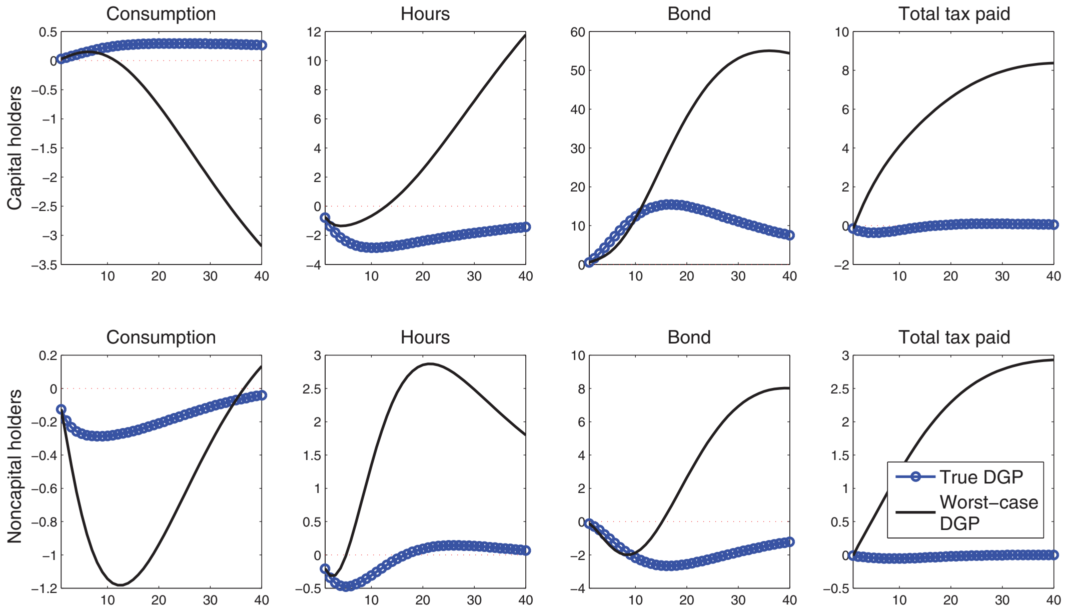
CAPITAL INCOME TAX UNCERTAINTY SHOCK: PATH OF FISCAL INSTRUMENTS UNDER THE TRUE AND WORST-CASE DGPS [COLOR FIGURE CAN BE VIEWED AT WILEYONLINELIBRARY.COM]

Figure 1 reports the model impulse responses to a capital income tax uncertainty shock. The heterogeneous agent model with limited participation (blue lines with circles) matches the VAR response quite well. The model predicts a drop in output, consumption, investment, and hours that is of a similar magnitude to the data. The model also replicates the reduction in real wages and inflation. To understand the mechanism of the heterogeneous agent model, in Figure 3, I report the paths of transfers, consumption, labor, and capital income taxes in response to the capital income tax uncertainty shock (blue lines with circles). I also report impulse responses under the worst-case beliefs (black solid lines): they describe the worst-case expected path that agents worry about when uncertainty increases. The worst-case capital income tax rate is heterogeneous: capital holders' worst case is high capital income tax whereas noncapital holders' worst case is low capital income tax. Given the estimated fiscal rules, the capital holders' high capital tax under the worst-case increases government revenue and thus raises transfers by 40% after five years under the worst case. To put this into perspective, transfers increase from 3.5% of steady-state output level to 4.9%. Consumption and labor taxes move less. For noncapital holders their worst-case scenario of low capital tax translates into low transfers.

Figure 4 reports the capital holders' and noncapital holders' consumption, hours, bond holdings, and total tax paid, which includes lump-sum transfers.[17] For both capital and noncapital holders, total tax paid increases under the worst-case belief.[18] Due to the perceived negative income effect, noncapital holders immediately cut their consumption by a sizable amount

[17] To be precise, total tax paid for the capital holders is given by $\tau_{c,t}C_t^c + \tau_{h,t}\int W_{i,t}H_{i,t}^c di + \tau_{k,t}(R_t^k - \delta)K_{t-1}^c - T_t^c$ and that of the noncapital holders is given by $\tau_{c,t}C_t^n + \tau_{h,t}\int W_{i,t}H_{i,t}^n di - T_t^n$.

[18] Capital holders receive back some portion of the higher capital income tax that they pay under the worst-case scenario as increased transfers. However, some of the capital tax paid will be redistributed to noncapital holders as transfers.



NOTES: The figure reports the impulse responses to a two-standard-deviations increase in σ_{τ_k} (capital income tax volatility). For consumption and hours, the units are in percentage deviations from the steady states. For bond holdings and total tax paid, the units are in percentage changes relative to the steady-state output level. The blue lines with circles and the black lines are the responses under the true and the worst-case DGPs, respectively, from the heterogeneous agent model with limited capital market participation.

FIGURE 4

CAPITAL INCOME TAX UNCERTAINTY SHOCK: INDIVIDUAL VARIABLES UNDER THE TRUE AND WORST-CASE DGPS
[COLOR FIGURE CAN BE VIEWED AT WILEYONLINELIBRARY.COM]

since they expect substantially lower consumption in the future. In the aggregate, the decline of consumption by noncapital holders outweighs the increase by capital holders and thus reduces aggregate demand and, through sticky prices, raises markups. This, in turn, depresses labor demand and lowers real wages. As a result, equilibrium employment and output drop substantially.[19]

As an external validation of the model, in Figure 2, I report how each agent's consumption response matches the CEX impulse response, which was not targeted in the estimation. The model not only matches the CEX data qualitatively (noncapital holders reduce consumption persistently whereas capital holders do not), but also *quantitatively*: the model impulse responses lie within the confidence bands for most horizons.

To highlight the role of limited capital market participation, I show in Figure 1 the impulse responses where I set the estimated share of noncapital holders (χ) to zero while holding other parameters at the original estimated values (purple lines). In response to an increase in uncertainty about the capital income tax, the representative household acts as if the future tax will be high. Facing lower after-tax return on capital, they substitute away from investment and increase consumption. Because of the intertemporal substitution of labor supply, households work less: lower perceived after-tax return on investment reduces the return on working. The increase in consumption, however, mitigates the decline in overall aggregate demand and thus

[19] In Figure 3, consumption and labor income taxes move sluggishly relative to the capital income tax under the worst-case DGP. For example, under the capital holders' worst-case DGP, labor income tax persistently decreases until it slowly reverts back to the steady state (not shown in the figure). This is because in the fiscal rule (3), taxes respond to government debt and the government debt itself is a slow-moving variable. In turn, the slow adjustment of consumption and labor income taxes causes capital holders' consumption and hours to persistently decrease or increase under their worst-case DGP until they revert back to their steady states.

equilibrium employment and output decline only mildly. At the same time, since hours fall without a large change in aggregate demand, markups also change little and hence real wages do not move. A different way to evaluate the contribution of limited capital market participation is to reestimate the model, subject to the constraint $\chi = 0$. The resulting impulse responses are shown in Figure 1 in red dashed lines. The representative agent model still has some difficulty matching the VAR. For example, the reduction in output and hours is milder than the limited participation model and consumption does not fall enough. The model also cannot replicate the decline in real wages. As a result, the limited capital market participation model beats the representative agent model in terms of marginal likelihood by 5 log points (the log marginal likelihoods are −568 and −573 for the limited participation and representative agent models, respectively).[20] In other words, the data prefer the heterogeneous agent model by a factor of (exp(5) =)148. These observations indicate that household heterogeneity due to limited capital market participation is a critical feature to explain the empirical effects of fiscal uncertainty shocks.

The Role of Ambiguity.
To understand the role of ambiguity in the transmission of fiscal uncertainty shocks, in Figure 5, I compare the impulse responses where the capital income tax uncertainty shock is transmitted through risk (but not through ambiguity), as in Fernández-Villaverde et al. (2015) and Born and Pfeifer (2014), and through ambiguity (the baseline model of this article). The risk model is solved using the third-order perturbation as in Fernández-Villaverde et al. (2015) and Born and Pfeifer (2014). In addition, in order to give the risk model a fair shot and to facilitate comparison with the literature, I calibrate the risk model's parameters for real and nominal rigidities and monetary policy rule to those used in Fernández-Villaverde et al. (2015).[21] The orange dashed lines are the impulse response of the representative agent version of the risk model, where I set the share of noncapital holders χ to zero. As in Fernández-Villaverde et al. (2015), output, consumption, investment, and hours decline in response to an increase in capital income tax uncertainty. However, the contraction in economic activity is too small relative to data. In addition, the model counterfactually predicts an increase in inflation and the nominal interest rate. I plot the impulse response of the risk model with limited capital market participation in light blue lines with x's. The household heterogeneity amplifies the fall in real activity generated by the uncertainty shock but the risk model still understates the magnitude compared to the VAR. In addition, the increase in inflation and the nominal interest rate is larger than the representative agent version of the risk model, further widening the discrepancy between the model and data for nominal variables.

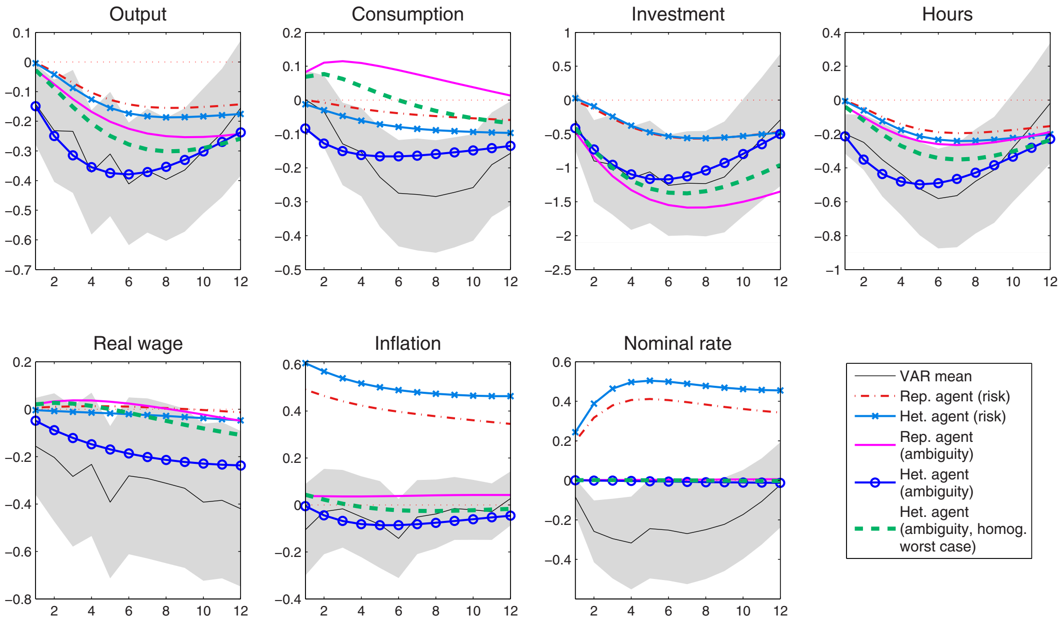
Another way to assess the role of ambiguity and its interaction with household heterogeneity is to consider the impulse response where I counterfactually set the worst-case scenarios for both capital and noncapital holders to a high capital tax. With a homogeneous worst-case scenario (green dashed lines in Figure 5), the responses of output, consumption, and hours are more pronounced in the medium run compared to the representative agent version of the ambiguity model (purple lines). However, in the short run the homogeneous worst-case model

[20] An alternative way to measure the fit of the model to data is to compute the loss function that is used to construct the likelihood function in the Bayesian impulse-response matching:

$$L = -0.5[\hat{\psi} - \psi(\theta)]' V^{-1} [\hat{\psi} - \psi(\theta)], \tag{13}$$

where $\hat{\psi}$ is the impulse response from the VAR, $\psi(\theta)$ is the model impulse response which depends on parameters θ, and V is the variance–covariance matrix for the sampling variance. For the capital income tax uncertainty shock, the measured losses L are −90, −340, and −123 for the heterogeneous agent model, the representative agent model without reestimation, and the reestimated representative agent model, respectively. These figures are −378, −737, and −400 when all four fiscal uncertainty shocks are included in the loss function.

[21] To be precise, I set $b = 0.75$, $\kappa = 0.75$, $\frac{1}{1-\xi_p} = 4$, $\frac{1}{1-\xi_w} = 4$, $\rho_R = 0.7$, $\phi_\pi = 1.35$, $\phi_Y = 0.25$ and set other parameters to estimated values in the baseline limited capital market participation model. When I set all parameters to the estimated values in the baseline model and simulate the risk model, I find that the impact of capital income tax uncertainty shocks on macro variables is negligible.



NOTES: The figure reports the impulse responses to a two-standard-deviations increase in σ_{τ_k} (capital income tax volatility). The units are in percents (annual percentage points for inflation and nominal rate). For the black lines, blue lines with circles, and purple lines, see notes for Figure 1. The responses from the rational expectations version of the model, where agents do not perceive ambiguity, are shown in orange dashed lines (representative agent) and light blue lines with x's (heterogeneous agent model). The green dashed lines are the responses from the heterogeneous agent model with ambiguity where I counterfactually set the noncapital holders' worst case to the capital holders' (high capital income tax).

FIGURE 5

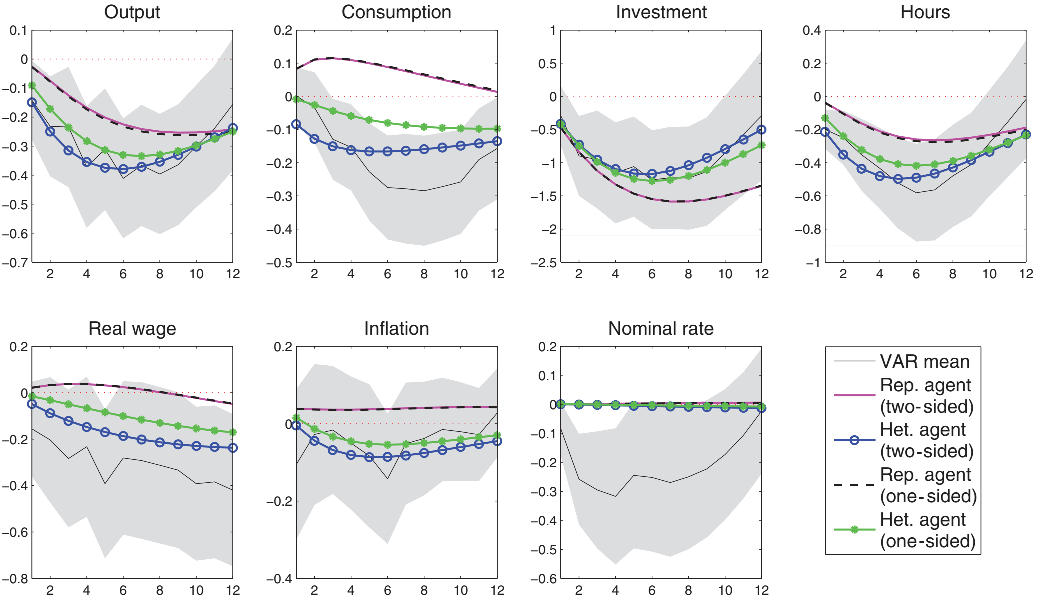
CAPITAL INCOME TAX UNCERTAINTY SHOCK: RISK VERSUS AMBIGUITY
[COLOR FIGURE CAN BE VIEWED AT WILEYONLINELIBRARY.COM]

generates little amplification and consumption increases instead of decreases. The decline in economic activity in the homogeneous worst-case model is smaller than the baseline model with heterogeneous worst-case scenario because noncapital holders perceive a positive income effect due to the anticipation of lower total taxes under the worst-case DGP.[22] To sum up, the heterogeneous agent version of the risk model understates the contraction in economic activity compared to the VAR as does the ambiguity model with limited capital market participation but with homogeneous worst-case scenarios. I conclude that heterogeneous worst-case scenarios, generated through the combination of household heterogeneity and Knightian uncertainty, are important for successively accounting for the impact of capital income tax uncertainty shocks.

One-Sided Uncertainty Shocks.

The capital income tax uncertainty shock I considered so far is two-sided: the upper and lower bounds of the belief set widen symmetrically. The advantage of my model, which models ambiguity about future fiscal policies through intervals of means, compared to the standard model with only risk, which models fiscal uncertainty through a mean-preserving spread in volatility, is that I can study the impact of one-sided uncertainty shocks. The exercise is useful for two reasons. First, since the standard two-sided uncertainty shock is a combination of one-sided uncertainty shocks, the exercise allows for a decomposition of the two-sided uncertainty shocks into two factors. Second, one-sided fiscal uncertainty shocks are in themselves interesting.

[22] In terms of the loss function (13), the homogeneous worst-case model is $L = -219$. Hence, it fits the empirical response to the capital income tax uncertainty shock better than the representative agent model (without reestimation) but worse than the heterogeneous agent model with heterogeneous worst-case scenarios.



NOTES: The figure reports the responses to a capital income tax uncertainty shock, but with the lower bound of the belief set fixed at the steady-state level. The units are in percents (annual percentage points for inflation and nominal rate). The green lines with stars are the responses from the baseline heterogeneous agent model with limited capital market participation. The black dashed lines are the responses from the representative agent model with full capital market participation where I set the share of noncapital holders χ to 0, while holding other parameters at the estimated values from the limited participation model. The blue lines with circles and the purple lines are the corresponding figures for the conventional two-sided uncertainty shocks in the heterogeneous agent and representative agent models, respectively. The black lines are the mean responses from the VAR and the shaded areas are the 95% confidence band.

FIGURE 6

ONE-SIDED UNCERTAINTY SHOCK: AN INCREASE OF UPSIDE UNCERTAINTY
[COLOR FIGURE CAN BE VIEWED AT WILEYONLINELIBRARY.COM]

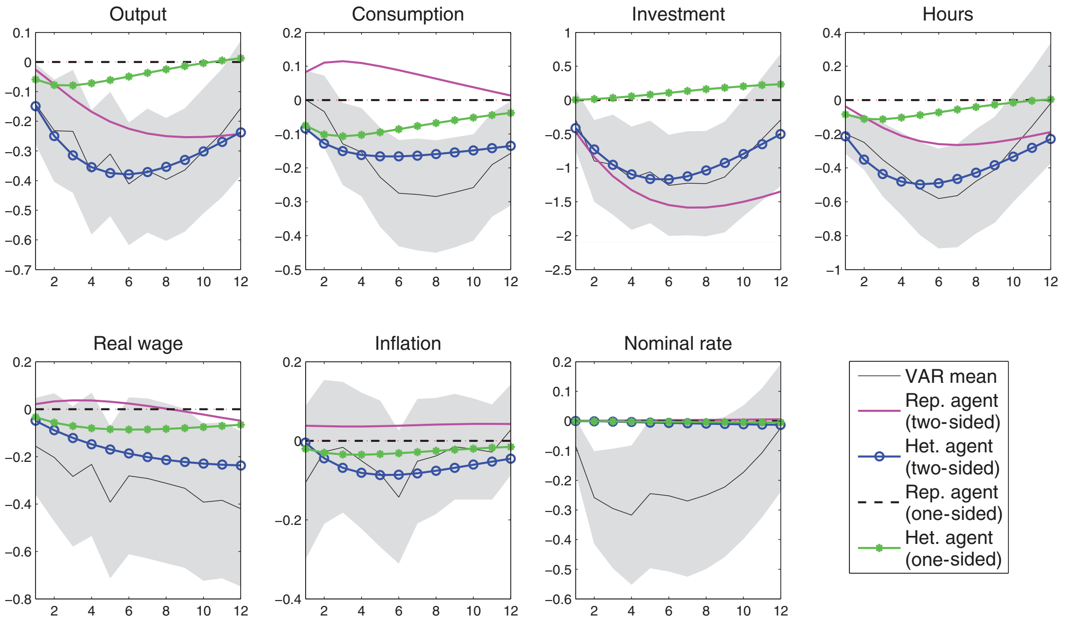
Indeed, historical events suggest that changes in fiscal uncertainty are often one-sided in nature (e.g., whether congress will pass a tax cut or not).

In Figure 6, I consider the impact of an increase in the upper bound of the belief set (an increase of upside uncertainty). The size of the increase in the upper bound is equal to that in the baseline specification of the two-sided uncertainty shock. Thus, the only difference from the two-sided case is that there is no change in the lower bound.[23] First, in the representative agent model, since the worst case is a high capital tax, the impulse response is identical to the case of a two-sided uncertainty shock. Second, even though the noncapital holders' worst case is fixed in the heterogeneous agent model, the fall in real activity is larger and generates comovement. This is because noncapital holders amplify the New Keynesian demand effect caused by the capital holders' reaction to the uncertainty shock. In Figure 7, I consider the impact of a lowering of the lower bound (an increase of downside uncertainty). In the representative agent model, there is no effect since the worst-case scenario for the representative agent is unchanged. In contrast, output, consumption, and hours fall in the heterogeneous agent model. Compared to the increase in upside uncertainty, the effect of downside uncertainty is less persistent and milder.

The Role of Monetary Policy.

The monetary policy plays an important role in shaping the response to a capital income tax uncertainty shock. To see this, in Figure 8, I consider a counterfactual impulse response where

[23] Note that this exercise is different from that of combining a two-sided uncertainty shock and a shift in the expectation, in which case the worst-case scenarios for both agents change.



NOTES: The figure reports the responses to a capital income tax uncertainty shock, but with the upper bound of the belief set fixed at the steady-state level. See notes from Figure 6 for additional details.

FIGURE 7

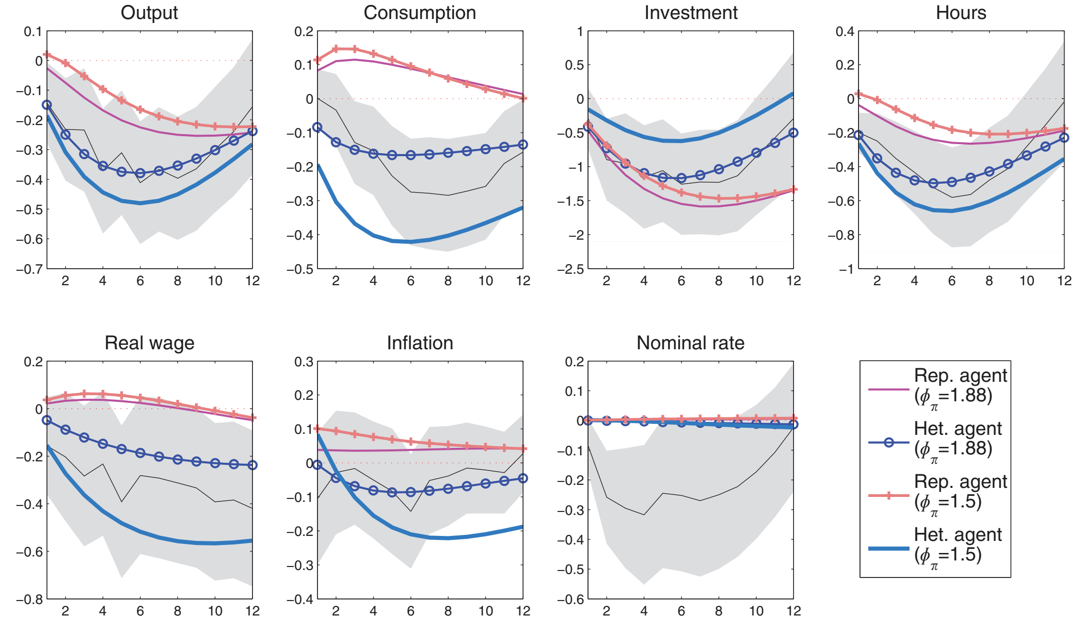
ONE-SIDED UNCERTAINTY SHOCK: AN INCREASE OF DOWNSIDE UNCERTAINTY
[COLOR FIGURE CAN BE VIEWED AT WILEYONLINELIBRARY.COM]

the central bank responds less strongly to inflation ($\phi_\pi = 1.5$ instead of $\phi_\pi = 1.88$). First, consider the heterogeneous agent model (light blue lines). Because the central bank tolerates deflation due to the consumption cut by noncapital holders, output, consumption, and hours decline more than under the baseline Taylor rule. For example, consumption falls by as much as 0.4% compared to less than 0.2% under the baseline Taylor rule. In contrast, in the representative agent model (peach-colored lines with "+"-signs), the alternative Taylor rule actually mitigates the reduction in economic activity relative to the baseline Taylor rule. The comparison of these counterfactual scenarios underscores the importance of taking household heterogeneity into account when conducting monetary policy analysis.

In the Online Appendix, I push this argument further and show how household heterogeneity matters for the transmission of a capital income tax uncertainty shock when the economy is stuck at the ZLB. Comparing the heterogeneous agent model under the Taylor rule and under the ZLB, the output response of the latter is much larger than the response of the former whereas in the representative agent model the responses under the two monetary regimes are very similar. In the heterogeneous agent model, the effect of capital tax uncertainty is larger under the ZLB because the central bank cannot lower the interest rate to counteract low aggregate demand due to the consumption cut by noncapital holders.

Uncertainty Shocks for Other Fiscal Instruments.

The main mechanism of this article—a redistributional concern amplifies the impact of the capital income tax uncertainty shock—extends to uncertainty shocks to other fiscal instruments. In Figure 9, I plot the VAR mean responses of aggregate variables to a two-standard-deviations increase in uncertainty about consumption tax as well as the estimated impulse response from the model. In the data, a consumption tax uncertainty shock generates reductions in output, consumption, and hours worked. Compared to the representative agent model, in the limited capital market participation model the contraction in output, consumption, and hours is more



NOTES: The figure reports the impulse responses to a two-standard-deviations increase in σ_{τ_k} (capital income tax volatility). The units are in percents (annual percentage points for inflation and nominal rate). The black lines are the mean responses from the VAR and the shaded areas are the 95% confidence band. The blue lines with circles are the responses from the baseline heterogeneous agent model with limited capital market participation. The purple lines are the responses from the representative agent model with full capital market participation where I set the share of noncapital holders χ to 0, while holding other parameters at the estimated values from the limited participation model. The light blue lines and the peach-colored lines with "+"-signs are the responses where I counterfactually set the inflation response of the Taylor rule to $\phi_\pi = 1.5$ for the heterogeneous agent and representative agent models, respectively.

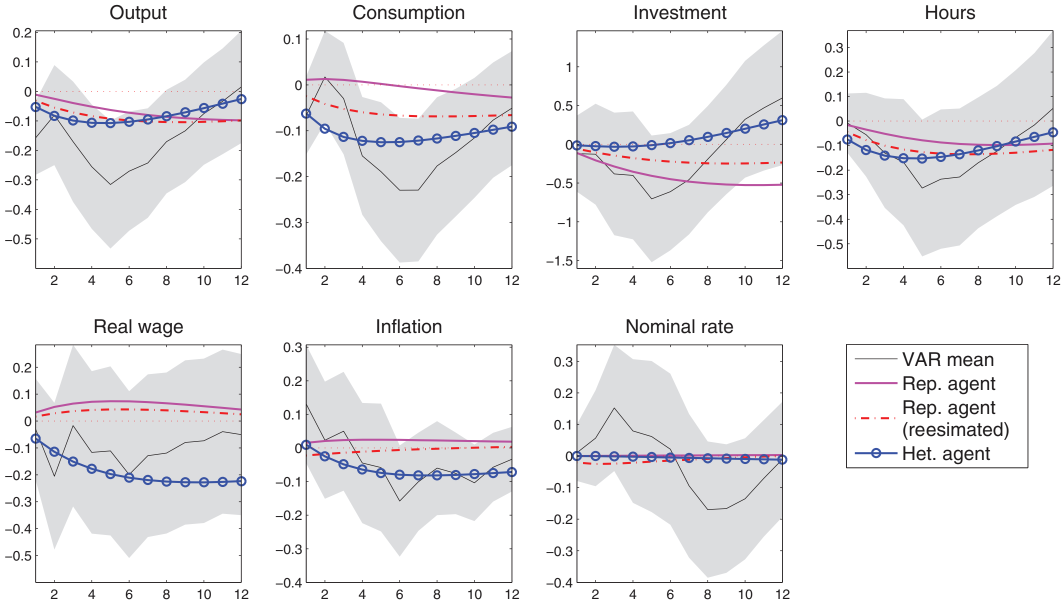
FIGURE 8

CAPITAL INCOME TAX UNCERTAINTY SHOCK: EFFECT OF TAYLOR RULE
[COLOR FIGURE CAN BE VIEWED AT WILEYONLINELIBRARY.COM]

pronounced.[24] As we saw in the case of the capital income tax uncertainty shock, the worst-case consumption tax is heterogeneous: capital holders fear high consumption tax whereas noncapital holders fear low tax. The worst case is heterogeneous because capital holders consume more than noncapital holders. For capital holders, the high consumption tax translates into higher total tax paid under their worst-case scenario. For noncapital holders, even though their consumption tax is lower under the worst-case belief, this lower tax translates into lower transfers due to lower government revenue and thus their total tax paid increases under the worst-case scenario. As a result, noncapital holders cut their consumption and thus aggregate demand falls. Due to nominal rigidities, this low demand translates into higher markups and thus lowers equilibrium hours and output. Figure 10 shows that the mechanism is consistent with the household-level evidence: both in the model and in the CEX data, noncapital holders reduce consumption whereas capital holders do not.

In contrast to capital income tax uncertainty and consumption tax uncertainty shocks, as I show in the Online Appendix, household heterogeneity does not lead to large amplification for government spending and labor income tax uncertainty shocks. This is because for both shocks the worst-case scenarios are homogeneous. In the case of the government spending uncertainty shock, since government spending is mainly financed by a lump-sum tax that is imposed equally

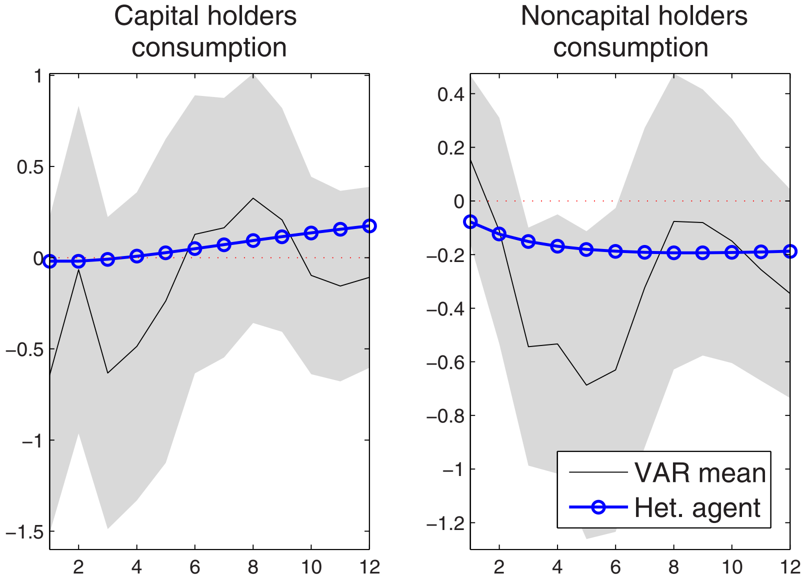
[24] For the consumption tax uncertainty shock, the measured losses L in (13) are -66, -145, and -96 for the heterogeneous agent model, the representative agent model without reestimation, and the reestimated representative agent model, respectively.



NOTES: The figure reports the impulse responses to a two-standard-deviations increase in σ_{τ_c} (consumption tax volatility). See notes from Figure 1 for additional details.

FIGURE 9

CONSUMPTION TAX UNCERTAINTY SHOCK: AGGREGATE VARIABLES
[COLOR FIGURE CAN BE VIEWED AT WILEYONLINELIBRARY.COM]



NOTES: The figure reports the impulse responses to a two-standard-deviations increase in σ_{τ_c} (consumption tax volatility). See notes from Figure 2 for additional details.

FIGURE 10

CONSUMPTION TAX UNCERTAINTY SHOCK: HOUSEHOLD-LEVEL CONSUMPTION
[COLOR FIGURE CAN BE VIEWED AT WILEYONLINELIBRARY.COM]

on both types of households, the worst-case scenario of both capital holders and noncapital holders is a higher government spending. Similarly, for the labor income tax uncertainty shock, the worst case is a higher tax for both agents. It is important to point out, however, that in richer models with stronger redistributional effects, household heterogeneity could have a larger impact on the transmission of these shocks. For example, if households are heterogeneous in their productivity and government spending is mainly financed by deficit as in Hagedorn et al. (2019), then government spending would involve redistribution through asset markets as high productivity households would lend their assets to the government. Alternatively, in models with locational heterogeneity, the provision of local public goods inherently generates winners and losers.

6. CONCLUSION

In this article, I proposed a transmission mechanism that magnifies the recessionary effect of an increase in fiscal uncertainty and demonstrated that it can account for some salient empirical features of the responses of macroeconomic and household variables to fiscal uncertainty shocks. In particular, I have shown that the limited capital market participation model captures agents' concern about redistribution that is absent in representative agent models. In my model, this redistribution concern has first-order effects because it shows up as heterogeneous worst-case beliefs that are parameterized by intervals of conditional means.

SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Figure A1: Fiscal volatility and uncertainty
Figure A2: Household-level consumption responses to a capital income tax volatility shock: splits based on holding of assets other than stocks
Figure A3: Household-level consumption responses to a property tax volatility shock: home owners vs renters
Figure A4: Estimated impulse response using Sims-Cogley-Nason approach
Figure A5: The role of price and wage rigidities
Figure A6: The role of price and wage markups
Figure A7: Effect of the zero lower bound
Figure A8: Government spending uncertainty shock
Figure A9: Labor income tax uncertainty shock
Figure A10: A simultaneous increase in uncertainty about all fiscal instruments

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